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COMPREHENSIVE PROGRESS REPORT

For the Period April 1, 1980 - March 31, 1981

THE INFLUENCE OF SILVICULTURAL PRACTICES ON THE SUSCEPTIBILITY AND VULNERABILITY OF NORTHERN ROCKY MOUNTAIN FORESTS TO THE WESTERN SPRUCE BUDWORM

Clinton E. Carlson and Ward McCaughey

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by

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1. TITLE: The Influence of Silvicultural Practices on the Susceptibility and Vulnerability of Northern Rocky Mountain Forests to the Western Spruce Budworm

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   d. Dr. Wyman Schmidt, Research Forester

4. ACTIVITY NUMBERS TO WHICH WORK IS ADDRESSED:

   a. 2.2.1 Determine relationships of site/stand characteristics and management practices to stand susceptibility and vulnerability.

   b. 2.3.1 Refine and improve stand projection model to include major budworm host types, with and without outbreak histories.

   c. 3.1.1 Determine how and to what extent WSBW damage affects forest resources and management plans.

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REVIEWS AND APPROVALS

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MR. THAD HARRINGTON — Date
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INTRODUCTION

It has been suggested that silvicultural strategies can be employed to reduce tree damage caused by the western spruce budworm, Choristoneura occidentalis Freeman. With this concept in mind, this 5-year study was designed to:

1. Identify silvicultural strategies that will minimize the impact of WSBW (western spruce budworm) on conifer regeneration in managed forests of the Northern Rockies;

2. Provide a quantitative data base with which to make critical decisions about WSBW damage to regeneration; and

3. Improve the state-of-knowledge of the complex interactions between WSBW, site and stand conditions, environmental gradients, vegetation types, and other biotic and abiotic factors.

This comprehensive report details the progress made during April 1, 1980-March 31, 1981, and specifically relates to the research proposal to CANUSA West, "The Influence of Silvicultural Practices on the Susceptibility and Vulnerability of Northern Rocky Mountain Forests to the Western Spruce Budworm," by Clinton E. Carlson, submitted in February 1980. Objectives for this period were:

1. Measure the effect of WSBW on height growth, vigor, and crown development of established conifer reproduction between ages 5 and 15 years in various harvest systems in the subalpine fir climax series; and

2. Determine if past WSBW activity has adversely affected the establishment of conifer regeneration relative to various silvicultural systems.

METHODS AND DESIGN

Selection of Stands

Data were collected from conifer stands between 5 and 15 years old which resulted from previous harvest cuts in the budworm-susceptible subalpine fir forest climax series present in Montana (fig. 1). Four regeneration cutting systems (clearcut, shelterwood, seed tree, and selection) were studied relative to two levels of budworm infestation (none-to-light and moderate-to-heavy). Units of three sizes were selected (<5 acres, 5-50 acres, and >50 acres), and two replicates were considered. It is stands of these types that the land manager--be he federal, state, or private--is very interested in from a silvicultural perspective relative to the effect of budworm. Thus, the design implies that 48 stands would be selected and studied in 1980 (one series x two budworm levels x four cutting systems x three unit sizes x two replicates).

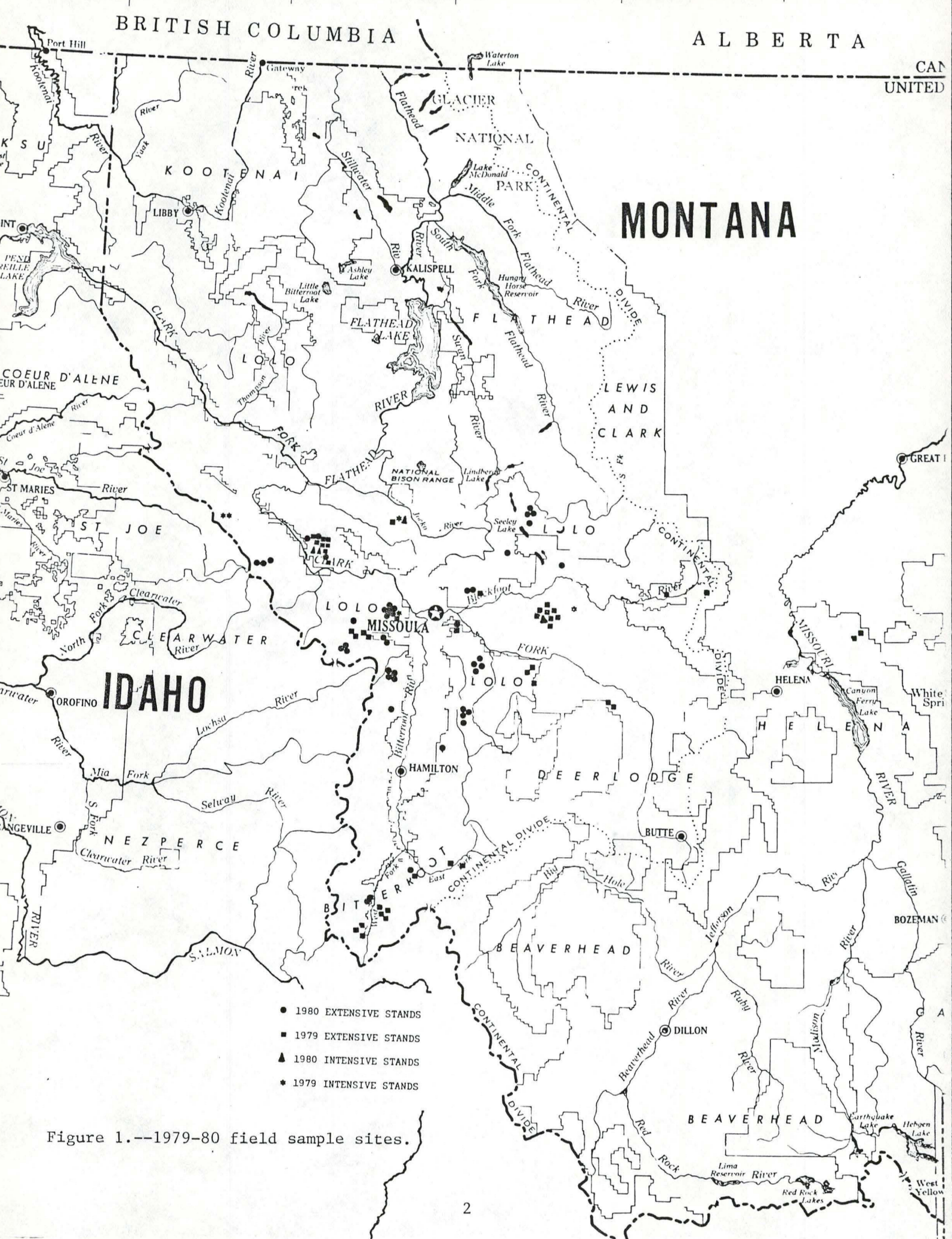

Figure 1.--1979-80 field sample sites.

Listings of candidate stands were obtained from Forest Service Regions 1 and 4, Bureau of Indian Affairs, Bureau of Land Management, Burlington Northern, Champion International, and the State of Montana. Based on field observations that WSBW has been moderate-to-heavy for 10-15 years in the Garnet Range east of Missoula and in the Bitterroot Range west of Missoula, we selected most of the infested study stands in these areas. Also, these areas have an extensive logging history, all of the silviculture methods we propose to consider are represented, and other intrinsic site factors, such as soils, elevations, aspects, slopes, and geological histories, are reasonably similar. Noninfested stands were selected primarily in the northern part of the Sapphire Range and in a portion of the west Bitterroot Range, which have had a history of little budworm, and which have site characteristics similar to stands in the infested areas.

Stands selected for study must have had a reasonably good quality of silviculture applied at time of cutting. We did not want to sample stands that were hygraded, leaving only the poorest material for seed source. Rather, for example, in a seed tree cut, one would select a stand in which average or better trees were left for the seed source and reasonably good site preparation was attempted. Initially, potential study sites were selected at random and field checked to assure that our basic criteria were met. If additional stands meeting the criteria were observed near the randomly selected stands, they also were selected for study.

Field Sampling

ADJACENT STANDS

The residual stand adjacent to the selected study stand was characterized. About five to seven variable-radius plots were established, and species composition, basal area, crown classes, crown ratios, heights, and diameters were recorded. All WSBW host trees within the variable plot were rated for defoliation, using the three-crown strata system agreed upon at the Lubrecht meeting.[1] The crown is visually separated into lower, middle, and upper. Each portion is then rated for WSBW defoliation and coded as follows:

Code	Description
0	No defoliation
1	Light defoliation
2	Moderate defoliation
3	Severe defoliation

These are subjective classes and reflect defoliation over a period of years--1 to 7 or 8--depending on the situation.

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[1]CANUSA meeting held at Lubrecht Experimental Forest in western Montana, May 16, 1979.

It is important that the history of WSBW in these adjacent stands be known. We assume that if WSBW has been intense enough to have caused a detrimental effect in the study stands, it also would have been adequately intense to have caused an observable effect on radial stem growth of residual host trees in the adjacent stands. We have collected and analyzed preliminary data that indicate, indeed, that this is the case. Therefore, from infested stands, two increment cores from each of three defoliated host trees and three nonhost trees were extracted, placed in plastic straws to prevent dehydration, and transferred to our laboratory where annual radial increment was measured and recorded. In noninfested stands, the same procedure was followed. In addition, the aerial survey maps of WSBW defoliation maintained by FI&DM in Region 1 were researched for histories of visible defoliation in belief we can develop a historical defoliation index for each stand by combining these data and that this index can then be utilized in analyses of the within-stand data.

SAMPLING WITHIN CUTTING UNITS

Plots 1/300 acre in size were established along a transect that encounters most of the recognized site variability. Stage (1973) used plots of this size in similar studies and found them adequate, and National Forest management routinely uses 1/300-acre plots in silvicultural examinations. Sampling error for a given variable within a matrix cell[2] should be within the confidence interval:

$$\bar{x} \pm T_{.05} (SE_{\bar{x}}), \text{ such that:}$$

$$\frac{T_{.05} (SE_{\bar{x}})}{\bar{x}} \leq .20$$

A number of variables known to influence conifer regeneration establishment, survival, and growth were measured at each plot. It is important that this study relate to and be understood by forest land managers. Therefore, many of the variables measured within each stand and plot are those variables routinely measured in stand examinations by foresters and silviculturists.[3]

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[2]A matrix cell is defined as any single combination of the stand selection criteria.

[3]See "Field Instructions, Stand Examination and Forest Inventory." Stand Examination Handbook FSH 2409.21, RI, Chapter 300. April 1978. USDA, Northern Region. 113 pp.

Each plot was unique as the sampling unit and all variables were quantified. Thus, the stand selection criteria were quantified and recorded as follows:

a. Forest climax series - habitat type by dummy variable

b. Budworm damage rating given to residual stand (Bousfield 1978[4]) and increment analysis as described above

c. Cutting system - Basal area of residual stand was estimated with a 10 BAF prism

d. Cutting unit size - acres

Intrinsic site variables measured and recorded at each plot were:

a. Aspect; degrees

b. Slope percent

c. Physiography; ridgetop, dry slope, moist slope, stream bottom, flat or bench

d. Site preparation - none; mechanical or burned

e. Relative position of suspected seed and WSBW source by bearing, distance, and angle from plot center

It is standard practice in National Forest management to consider the dominant two established seedlings on each 1/300-acre plot as "management trees," or those seedlings most likely to become the preferred crop trees. Therefore, the following data, known to be silviculturally important, were collected from the two tallest established trees on each plot and recorded:[5]

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[4]The actual method was determined at a joint field meeting of the Moscow and Missoula INT Laboratories. Personal communication with Wayne Bousfield, FPM, Region 1 Forest Service, Missoula, MT.

[5]Details of these measured variables are presented in our 1980 continuing research proposal to CANUSA West, "The Influence of Silvicultural Practices on the Susceptibility and Vulnerability of Northern Rocky Mountain Forests to the Western Spruce Budworm."

a. Height from ground line to the bud scar of the previous year, in 0.1 foot

b. Species

c. Age - sample trees were cut at ground line and annual rings tallied

d. Dead or alive

e. Established or nonestablished

f. Vigor - height growth during past 5 years, 0.1 foot

g. Advanced growth or subsequent

h. Planted or natural

i. Crown position

j. Crown width, 0.1 foot

k. Crown length, 0.1 foot

ℓ. D.b.h., inches

m. Growth of current year - 0.1 foot

It was also important to assess the relationship of budworm to nonmanagement trees, or those seedlings that would not be carried through a rotation. Does WSBW preferentially damage intermediate crown classes or the dominants, or is there no difference? Therefore, all conifer seedlings, other than the two tallest, were tallied, and the following information was recorded:

a. Species

b. Crown position

c. Height to nearest 0.1 foot

d. Growth of current year - 0.1 foot

The incidence of budworm defoliation on regeneration is an indication of the relative influence of silvicultural system on budworm susceptibility and vulnerability of management and nonmanagement regeneration. Damage data provide direct evidence of the feeding preference of budworm and the responses of seedlings to budworm pressure. Budworm feeds differently on western larch than on other conifer hosts; therefore, assessment techniques differ. The following sampling methods developed and tested in 1978-79 were utilized in 1979-80 to assess current WSBW damage on host seedlings.

a. Douglas-fir, grand fir, subalpine fir, and Engelmann spruce--tallest (management seedlings)

The crowns were visually separated into three equal parts: upper, middle, and lower. A maximum of six shoots within each crown level were evaluated for current and previous WSBW defoliation and rated as follows:

Percent Defoliation	Code
0	0
1-25	1
26-50	2
51-75	3
76-99	4
100	5

Shoots were selected about equally around the crown, and percent defoliation was recorded for both current and previous years. Data for each shoot was recorded. A mean index and proportion damaged was then computed and recorded for each tree.

b. Western larch management seedlings

Fascicular damage. Each tree crown was visually separated into three portions. Within each portion, 33 dwarf shoots (fascicles) were observed, and the number of fascicles with WSBW feeding evidence was recorded. An average for the tree was derived and entered.

Lateral shoots. Ten current-year lateral shoots from upper crown were examined and the number of shoots fitting each of the following criteria was recorded:

	Type of Damage	Code
a.	No damage	0
b.	Needle-feeding only	1
c.	External shoot-mining	2
d.	Severed shoots	3

In all cases, only the most severe type of damage was recorded.

Terminal leader. Damage to terminal leaders was recorded on Field Sheets 4 and 1, as follows:

	Type of Damage	Code
a.	No damage	0
b.	Needle-feeding only	1
c.	External shoot-mining	2
d.	Severed terminal	3

c. Excess seedlings (established and nonestablished), all host species

The entire seedling was subjectively rated for defoliation, coded, and recorded on Field Sheet 1, as follows:

Defoliation	Code
0	0
1-25%	1
26-50%	2
51-75%	3
76-99%	4
100%	5

It is recognized that agents other than budworm may be responsible for seedling damage; the following general damage codes were entered:

Damage Agent	Code
a. Budworm	0
b. Weather	1
c. Animal	2
d. Other insect	3
e. Disease	4
f. Healthy	5

WESTERN SPRUCE BUDWORM POPULATION SAMPLING

Estimates of WSBW egg masses and defoliation were made at 29 locations according to CANUSA West minimum standards. These locations were:

1. All intensive sites (8)

2. All study sites of Shearer and Tiernan[6] (21)

Collection sites are listed in table 1. The studies of Tiernan, Shearer, and Carlson were conducted under a team concept at the Forestry Sciences Laboratory in Missoula; the collection of egg mass and defoliation data for all three studies was assigned to Carlson.

[6]Shearer, R. C. and C. F. J. Tiernan. 1980. Assess effects of WSBW feeding and defoliation on cone and seed production within the Northern Rocky Mountains. Research Proposal to CANUSA West.

Table 1.--1980 egg mass and defoliation collection sites

Intensive Sites

Unit number	Unit code	Location name
126	6C	Valley Creek #1
127	7C	Blue Mountain
135	9C	Chamberlain Creek
147	5B	Lubrecht
200	10A	First Creek
205	10B	Second Creek
210	10C	Valley Creek #2
215	10D	Union Peak

Cone and Seed Sites

Unit No.	Unit code	Location name	Unit No.	Unit code	Location name
031	1A	Lost-Bond Creek	203	2B	Pistol Creek
043	2A	Skidoo Creek	240	3B	Rainbow Lake
126	3A	Lake Mary Ronan	173	4B	Kelly Creek (Targhee)
120	4A	Truman Creek	*107	6B	Ashby Creek
178	5A	E. Dry Creek (Targhee)	059	7B	Thunderbolt Creek
234	6A	Ruby Creek	*116	8B	Spring Creek
104	7A	Gold Creek	160	9B	Magpie Creek
057	8A	Coney Peak	155	1C	Squaw Creek
133	9A	Bassoo Creek	163	2C	Ruby Mine
054	1B	Truman Peak	*141	3C	Richmond Ridge
*220	5D	W. Fork Lolo Creek			

NOTE: New unit codes were created to eliminate duplicate unit numbers of existing and future study sites.

*1980 cone and seed intensive sites

At each site, CANUSA minimum standards were followed:

1. Three plots were established at each site, each plot consisting of three WSBW host trees of dominant or codominant status.

2. The crown of each tree was conceptually divided into thirds, and percent defoliation was estimated in 5-percent increments for current and past defoliation.

3. Four branches were collected from midcrown of each tree and represented the four cardinal directions. Two of these were 70 cm in length; two were 40 cm. Twenty-five current shoots from the apical 40 cm of each shoot were rated for defoliation as follows:

Code	Defoliation Class
0	0
1	1-25%
2	26-50%
3	51-75%
4	76-99%
5	100%

In addition, defoliation was similarly rated along the main axis of each collected branch for current growth and for each of the preceding 5 years.

All defoliation rating was done onsite in the field. When this task was done, branches were bagged and kept separate by tree, plot, and stand, transferred to the FI&DM (Forest Insect and Disease Management) laboratory of Region 1, Forest Service, Missoula, and analyzed under ultraviolet light for egg mass density. Results were given in number of new and old egg masses per 1,000 square centimeters of foliage.

Intensive versus Extensive Sites

The major effort of this research was to visit and characterize as many different stands as possible within given funding restraints. Therefore, most stands were observed only once--they are the "extensive" stands. However, it will be of considerable interest to annually remeasure plots established in certain stands. These are termed the "intensive" sites. Data from these sites will be used to calibrate growth data from the extensive stands.[7]

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[7]A more detailed description of the relationship of intensive to extensive sites is given in "Interim Report to CANUSA West" by C. E. Carlson, Jan. 1981.

One clearcut, one selection, one seed tree, and one shelterwood stand were selected as additional intensive sites. Within each of these units, regeneration data and residual stand data (within and adjacent) were collected on plots established by the procedure outlined previously. Each plot was permanently marked and referenced, and the two tallest management trees were tagged so that they could be found and measured in future years.

Data Analysis

The null hypotheses being tested are:

1. WSBW does not influence conifer regeneration establishment

2. WSBW does not influence conifer regeneration growth

3. WSBW defoliation is not different on different species

4. Regeneration cutting system does not affect budworm activity

5. Unit size is not related to budworm damage to regeneration

Simple and multiple regression and nonparametric techniques are being utilized to analyze the data. Independent variables include forest climax series, budworm infestation level, residual basal area, unit size, and distance to seed source. Dependent variables will include seedling density, probability of stocking, and damage. Covariates in the analysis include the intrinsic site variables such as slope, aspect, physiography, etc. Specific models are presented in RESULTS AND PROGRESS.

RESULTS AND PROGRESS

This continuing study was originally conceived to collect and analyze regeneration data from three forest series: Douglas-fir, subalpine fir, and grand fir. There are four main functional aspects to such a study once it is funded. They are:

1. Collect and record field data

2. Enter data on punch cards, establish computer files, correct and edit data

3. Analyze and interpret data

4. Publish and/or report results

These functional aspects overlap forest series in our study because each series was dealt with in a separate, successive year: Douglas-fir in 1979, subalpine fir in 1980, and grand fir in 1981. For data collected in a given year, it has taken us until late December to read the increment cores, keypunch all data, and establish the data files. Data analysis then is done during spring of the following year. Therefore, this Progress Report deals with analysis of data collected in 1979 from the Douglas-fir series and status of data collected in 1980 from the subalpine fir series.

Analysis of Douglas-fir Series Data

CUTTING SYSTEM AND SEEDLING DAMAGE

A nonparametric analysis was done to test the relationship of WSBW damage on seedlings to the type of harvest cut applied. This was a first attempt at sorting out some general relationships between stand structure and WSBW activity. Three damage variables were analyzed: proportion shoots damaged, current damage, and past damage. Proportion shoots damaged was recoded to the five classes by which current and past damage were assessed, which were:

Class	Definition
0	No defoliation
1	1-25% defoliation
2	26-50% defoliation
3	51-75% defoliation
4	76-99% defoliation
5	100% defoliation

Cutting systems were clearcut, seed tree, shelterwood, and selection; each was characterized by mean residual basal area and trees per acre. The analysis was done for each species. Because sufficient data was available only for Douglas-fir and western larch seedlings, only these species are considered here. Also, only seedlings less than or equal to 15 years of age were considered. The number and percentage of seedlings within each of the damage codes by cutting system was computed for each variable. A seedling damage index (SDI) was computed for each species within cutting system and is defined as the sum of the products of class means and number of seedlings within the class, divided by the total number of seedlings observed for the cutting system. Class means are:

Class	Class mean, % damage
0	0
1	13
2	38
3	63
4	87.5
5	100

Thus, the seedling damage index actually is the average percent damage over all data from the cutting system. Data for proportion damaged are given in table 2; for current damage in table 3; and for past damage in table 4. Each cutting system is defined also by the density of host residual left following the cut; values of trees per acre and basal area per acre are given in tables 2-4.

Proportion shoots fed on by WSBW increased as residual basal area increased; the most pronounced difference was between clearcut and the other cutting systems. The same trend is noted for the current damage SDI except that it decreases in the selection cuts. Past WSBW SDI was approximately equal between clearcuts and seed tree cuts, increased in shelterwoods, and decreased in selection cuts, similar to the trend noted for current SDI. The SDI's computed are low, indicating that WSBW activity on seedlings was generally light in our stands during 1978 and 1979 and treatment differences would be difficult to separate. Even so, in consideration of tables 2-4, there appears to be some support to the hypothesis that WSBW damage on regeneration varies directly with the amount of host overstory left following harvest. The anomaly noted for selectively cut stands may be explained in that a greater number of age classes and sizes of residual are left relative to clearcuts, seed tree cuts, and shelterwood cuts. Thus, larval interception by residual would be greater in selection cuts, reducing the number of larvae that potentially would be received by the seedlings. We are in the process of analyzing and testing stand structure relative to this hypothesis.

Table 2.--Number of established management Douglas-fir seedlings in various classes of proportion shoots damaged

Cutting system	Residual $\bar{x}$ TPA[1]	Residual $\bar{x}$ BAA[2]	Classes of proportion shoots damaged: 0 No.	0 %	1 No.	1 %	2 No.	2 %	3 No.	3 %	4 No.	4 %	5 No.	5 %	Total seedlings	Seedling damage index[3]
Clearcut DF[4]	1.67	0.87	24	31.6	20	26.3	24	31.6	6	7.9	2	2.6	0	0	76	22.70
Seed Tree DF	19.19	7.07	4	7.8	21	41.2	16	31.4	8	15.7	2	3.9	0	0	51	30.59
Shelterwood DF	21.50	10.30	2	11.8	6	35.3	5	29.4	4	23.5	0	0	0	0	17	30.59
Selection DF	39.75	23.52	7	25.9	7	25.9	4	14.8	6	22.2	3	11.1	0	0	27	32.72

[1]TPA = Mean trees/acre.

[2]BAA = Mean basal area per acre.

[3]Seedling damage index = $\frac{\Sigma(\text{class } \bar{x} * \text{No. of seedlings})}{\text{Total seedlings}}$; Class Means are: 0-0% 3-63% 1-13% 4-87.5% 2-38% 5-100%

[4]DF = Douglas-fir.

Table 3.--Number of western larch and Douglas-fir seedlings in six classes of current damage over four silvicultural systems[1]

Cutting system	Residual		Current damage class												Total seedlings	Seedling damage index[4]
			0		1		2		3		4		5			
	$\bar{x}$ TPA[2]	$\bar{x}$ BAA[3]	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%		
Clearcut																
WL[5]	0.08	0.07	16	94.1	1	5.9	0	0	0	0	0	0	0	0	17	
DF	1.67	.87	242	58.5	161	38.9	10	2.4	1	0.2	0	0	0	0	414	
All Host	1.75	0.95	258	62.3	162	40.3	10	2.4	1	0	0	0	0	0	431	5.91
Seed Tree																
WL	2.64	3.36	31	24.8	71	56.8	22	17.6	1	0.8	0	0	0	0	125	
DF	19.19	7.07	388	55.0	261	37.0	49	6.9	7	1.0	1	0.1	0	0	706	
All Host	21.83	10.43	419	50.0	332	40.0	71	9.0	8	1.0	1	0	0	0	831	9.15
Shelterwood																
WL	1.45	0.91	1	12.5	7	87.5	0	0	0	0	0	0	0	0	8	
DF	21.50	10.30	71	27.2	159	60.9	20	7.7	9	3.4	2	0.8	0	0	261	
All Host	22.95	11.21	72	26.9	166	61.7	20	7.4	9	3.3	2	0.1	0	0	269	13.60
Selection																
WL	3.71	2.96	11	52.4	10	47.6	0	0	0	0	0	0	0	0	21	
DF	39.75	23.52	207	53.6	144	37.3	29	7.5	5	1.3	1	0.3	0	0	386	
All Host	43.46	26.48	218	53.6	154	37.8	29	7.1	5	1.2	1	0	0	0	407	8.62

[1]Includes established management, established nonmanagement, and nonestablished seedlings.

[2]TPA = Mean trees/acre.

[3]BAA = Mean basal area per acre.

[4]Seedling damage index = $\frac{\Sigma(\text{class } \bar{x} * \text{No. of seedlings})}{\text{Total seedlings}}$; Class Means are: 0-0% 3-63%, 1-13% 4-87.5%, 2-38% 5-100%

[5]WL = western larch; DF = Douglas-fir.

Table 4.--Number of Douglas-fir seedlings in six classes of past damage over four silvicultural systems[1]

Cutting system	Residual $\bar{x}$ TPA[2]	Residual $\bar{x}$ BAA[3]	Seedling damage class 0 No.	0 %	1 No.	1 %	2 No.	2 %	3 No.	3 %	4 No.	4 %	5 No.	5 %	Total seedlings	Seedling damage index[4]
Clearcut DF[5]	1.67	.87	23	30.7	50	66.7	2	2.7	0	0	0	0	0	0	75	9.68
Seed Tree DF	19.19	7.07	16	30.2	37	69.8	0	0	0	0	0	0	0	0	53	9.07
Shelterwood DF	21.50	10.30	3	17.6	12	70.6	2	11.8	0	0	0	0	0	0	17	13.65
Selection DF	39.75	23.52	3	11.1	20	74.1	4	14.8	0	0	0	0	0	0	27	5.63

[1]Includes established management, established nonmanagement, and nonestablished seedlings.

[2]TPA = Mean trees/acre.

[3]BAA = Mean basal area per acre.

[4]Seedling damage index = $\frac{\Sigma(\text{class } \bar{x} * \text{No. of seedlings})}{\text{Total seedlings}}$; Class Means are: 0-0% 3-63% 1-13% 4-87.5% 2-38% 5-100%

[5]DF = Douglas-fir.

REGRESSION OF SEEDLINGS PER PLOT ON VARIOUS SITE FACTORS

The number of seedlings existing on a 1/300-acre plot depends on interactions between the quantity of seed reaching the plot through time, intrinsic site factors, weather affecting germination and establishment of the seedlings, and various insects and diseases which influence seed production, dissemination, and germination. Because in this study we observed the extensive plots at one point in time, it was impossible to reconstruct at each plot the series of events leading to the current seedling composition. Rather, the approach was to sample a large number of plots representing a time line of 5-15 years over randomly varying site and stand conditions. Through this type of data base we intend to empirically develop the dominant relationships leading to regeneration of various sites, and be able to isolate the effect of WSBW on the regeneration process.

Our hypothetical model is:

$$Y_{ijk\ell mnopqrs} = \alpha + \delta_{1i}S_{1i} + \delta_{2i}S_{2i} + b_1A_j + b_2B_k + b_3Z_\ell + B_4J_m + b_5W_n + b_6D_o + b_7F_p + b_8E_q + b_qT_r + \theta_{1s}P_{1s} + \theta_{2s}P_{2s} + \theta_{3s}P_{3s} + \theta_{4s}P_{4s} + e_{ijk\ell mnopqrs}$$

where:

$Y_{ijk\ell mnopqrs}$ = number of seedlings of a species within a 1/300-acre plot

and

S_i = Site preparation (dummy variable)

A_j = Years since harvest

B_k = Overstory basal area at plot (for species), square feet per acre

Z_ℓ = Overstory basal area within stand (for species), $\bar{x}$ sq. ft. per acre

J_m = Overstory basal area in adjacent stand (for species), $\bar{x}$ sq. ft./acre

W_n = Western spruce budworm hazard index for stand

D_o = Slope * sin (aspect)

F_p = Slope * cos (aspect)

E_q = Elevation of stand, feet mean sea level

T_r = Tangent of slope

P_s = Physiography of plot (dummy variable)

The overstory variables are surrogates for numbers of seed reaching a plot, site prep relates information about the quality of seedbed following harvest, and WSBW hazard index represents potential effects of the insect on seed production and seedling establishment (Carlson and McCaughey 1981).

Stage (1976) explained the use of sine and cosine transformations of aspect; we believe his rationale is applicable to seedling establishment as well as growth. The slope, aspect, and physiography variables serve to identify intrinsic site quality for plots.

A rather large number (39) of habitat types were represented in our 922 plots. Many of these were represented by only one or a few occurrences and would add little to the understanding of this complex problem if analyzed separately. Therefore, based on data of Pfister and others (1977), interpretations of Pfister and Shearer (1977), and Fiedler's report (1980), plots were grouped by habitat types with similar productivity, site index, and stocking probabilities. Three groups, high (group 1), medium (group 2), and low (group 3) were recognized and are shown in table 5. Separate regressions were run on each group according to the model previously described. One regression was also done irrespective of habitat type; all groups were combined and the model was tested without habitat type as a variable. This was done to see whether grouping habitat types would result in model improvement.

Table 5.--Habitat type groups[1]

Habitat code	Type name[2]	Frequency	Site index of Douglas-fir
GROUP I			
10	Scree	5	38 ± 6[2]
210	PSME/AGSP	16	
230	PSME/FESC	1	44 ± 7
281	PSME/VAGL,VAGL	34	44 ± 4
282	PSME/VAGL,ARUV	36	
283	PSME/VAGL,XETE	59	
311	PSME/SYAL,AGSP	42	
312	PSME/SYAL,CARU	134	
313	PSME/SYAL,SYAL	39	52 ± 4
321	PSME/CARU,AGSP	33	
322	PSME/CARU,ARUV	33	
323	PSME/CARU,CARU	60	47 ± 6
324	PSME/CARU,PIPO	4	
330	PSME/CAGE	13	
340	PSME/SPBE	1	49 ± ?
350	PSME/ARUV	12	
690	ABLA/XETE	3	40 ± 6
691	ABLA/XETE,VAGL	4	
692	ABLA/XETE,VASC	3	
720	ABLA/VAGL	5	
750	ABLA/CARU	3	
TOTAL 21		540	
GROUP II			
261	PSME/PHMA,PHMA	131	58 ± 6
262	PSME/PHMA,CARU	93	
291	PSME/LIBO,SYAL	6	56 ± 6
292	PSME/LIBO,CARU	14	
293	PSME/LIBO,VAGL	43	
250	PSME/VAGL	3	51 ± 6
510	ABGR/XETE	17	
661	ABLA/LIBO,LIBO	16	46 ± 9
662	ABLA/LIBO,XETE	10	
670	ABLA/MEFE	12	50 ± 8
TOTAL 10		345	
GROUP III			
440	PICEA/GATR	1	
521	ABGR/CLUN	26	71 ± ?
523	ABGR/CLUN,XETE	1	
530	THPL/CLUN	2	66 ± ?
531	THPL/CLUN,CLUN	2	
621	ABLA/CLUN,CLUN	2	66 ± 7
625	ABLA/CLUN,MEFE	1	
630	ABLA/GATR	2	
TOTAL 8		37	

[1]Personal communication with Dr. Robert Pfister, Forestry Sciences Laboratory, USDA Forest Service, Missoula, MT.

[2]Pfister and others 1977.

In all models reported below, the dependent variable is the number of natural, subsequent, established and nonestablished Douglas-fir seedlings per plot; there were 922 plots observed in 1979. Also, all variables were "forced" into the model regardless of their significance.

Regression 1. All Habitat Type Groups Combined

The regression was significant at $p < .01$ but the low coefficient of determination (R^2) of 0.079 indicates that little of the variability was explained by the independent variables included in the model. An examination of standardized predicted $\hat{Y}$ values against standardized residuals showed a very slight tendency of pattern. A regression summary is presented in table 6.

The most important partial regression coefficients, as inferred from F statistics, were mean basal area of residual Douglas-fir in the adjacent stand, tangent of slope, slope * cosine aspect, and physiography; this was not unexpected. However, we did not expect that stand age would be an insignificant variable. Douglas-fir seedling density should increase with time.

Table 6.--Summary statistics, R^2, and analysis of variance for regression #1

Summary Statistics

Variable name	Model ident.	Mean	Standard dev.	Cases
DFLINGS	Y	1.6920	3.1254	922
AGE	A	11.7191	2.9329	922
BAF03	B	9.7614	25.9990	922
DFIBA	Z	16.4948	17.8646	922
DFOBA	J	65.4939	43.4302	922
HAZIDX	W	1.3786	1.0631	922
SLOPTAN	T	.3198	.1757	922
SLOPSIN	D	.0261	.2579	922
SLOPCOS	F	.0022	.2570	922
ELEV	E	5019.4143	682.1300	922
D1	S_1	.5195	.4999	922
D2	S_2	.2852	.4518	922
D3	P_1	.0195	.1384	922
D4	P_2	.6800	.4667	922
D5	P_3	.1876	.3906	922
D7	P_4	.0926	.2970	922

R^2	
Multiple R	.28051
R square	.07869
Standard Error	3.02466

Analysis of Variance

Source	DF	Sum squares	Mean square	F
Regression	15	707.90482	47.19365	5.1585
Residual	906	8288.61579	9.14858	

Variables in the Equation

Variable	B	Beta	Standard error B	F
D7	.7095347+000	.06741	.88020	.650
AGE	-.3175873-001	-.02980	.04166	.581
BAF03	.2545466-002	.02117	.00436	.341
DFIBA	-.1176259-002	-.00672	.00739	.025
DFOBA	.5032944-002	.08383	.00268	5.054
HAZIDX	.1619305+000	.05508	.10632	2.320
SLOPTAN	-.2210838+001	-.12432	.67832	10.623
SLOPSIN	-.1257879+000	-.01038	.40201	.098
SLOPCOS	.2955236+001	.24304	.41539	50.615
ELEV	.1899075-003	.04145	.00018	1.119
D1	-.3180860-001	-.00509	.29558	.012
D2	.6016020-001	.00870	.32541	.034
D3	.9728788-000	.04309	1.09239	.793
D4	.1032325+001	.15416	.83416	1.532
D5	.1779534+001	.22242	.85912	4.290
(constant)	.6613389-001			

Regression 2. Habitat Type Group I

This regression was significant at $p \leq .01$. Some improvement in R^2 (0.105) was obtained over regression 1 but very little of the variability has been explained (see table 9). Standardized predicted $\hat{Y}$ values were plotted against standardized residuals; a slight tendency to pattern was observed similar to that which occurred in model 1. The regression summary is given in table 7. The most important variables entering the regression were slope * cosine aspect, basal area of Douglas-fir in the adjacent stand, and physiography; however, only the first was statistically significant. Stand age again was not significant.

Table 7.--Summary statistics, R^2, and analysis of variance for regression #2

Summary Statistics

Variable name	Model ident.	Mean	Standard dev.	Cases
DFLINGS	Y	1.6620	3.3200	539
AGE	A	11.7403	2.6498	539
BAF03	B	8.9054	18.5964	539
DFIBA	Z	17.0792	14.5087	539
DFOBA	J	72.3343	41.1271	539
HAZIDX	W	1.3574	1.0355	539
SLOPTAN	T	.2844	.1770	539
SLOPSIN	D	.0077	.2380	539
SLOPCOS	F	-.0504	.2304	539
ELEV	E	5170.3154	729.0380	539
D1	S_1	.5176	.5002	539
D2	S_2	.3043	.4605	539
D3	P_1	.0167	.1283	539
D4	P_2	.6883	.1636	539
D5	P_3	.1354	.3425	539
D7	P_4	.1521	.3595	539

R^2

Multiple R	.32425
R square	.10514
Standard Error	3.18531

Analysis of Variance

Source	DF	Sum squares	Mean square	F
Regression	15	623.44003	41.56267	4.09
Residual	523	5306.44865	10.14617	

Variables in the Equation

Variable	B	Beta	Standard error B	F
D7	.1954692+001	.21165	1.64677	1.409
AGE	.1586379-001	.01266	.06756	.055
BAF03	.1065685-001	.05969	.00802	1.764
DFIBA	-.9108695-002	-.03981	.01165	.611
DFOBA	.5389709-002	.06677	.00399	1.823
HAZIDX	.6672303-001	.02081	.16362	.166
SLOPTAN	-.9161624+000	-.04883	.99169	.853
SLOPSIN	.6060334+000	.04345	.62707	.934
SLOPCOS	.3999552+001	.27751	.62923	40.403
ELEV	-.1562909-003	-.03432	.00025	.400
D1	-.4879210+000	-.07351	.41742	1.366
D2	-.3855520+000	-.05348	.44668	.745
D3	.1270355+001	.04908	1.92750	.434
D4	.2374085+001	.33153	1.63272	2.114
D5	.2146730+001	.22147	1.67007	1.652
(constant)	.4520107+000			

Regression 3. Habitat Type Group II

This regression also is significant at $p \leq .01$; R^2 is quite low, 0.148, again indicating that little of the total variation is explained by the set of variables selected. The regression summary is in table 8. Residuals were as in models 1 and 2. Basal area of overstory Douglas-fir in the adjacent stand, slope tangent, slope * sine aspect, slope * cosine aspect, elevation, site preparation, and physiography were the more important independent variables relating to density of Douglas-fir seedlings. The "F" value for age is much higher (but not significant) in this regression. Possibly, the better site conditions in habitat type group II are better for continuous regeneration establishment.

Table 8.--Summary statistics, R^2, and analysis of variance for regression #3

Summary Statistics

Variable name	Model ident.	Mean	Standard dev.	Cases
DFLINGS	Y	1.7572	2.9120	346
AGE	A	11.7977	3.4024	346
BAF03	B	11.9075	35.3099	346
DFIBA	Z	17.1421	22.3115	346
DFOBA	J	57.5989	44.7531	346
HAZIDX	W	1.3976	1.1461	346
SLOPTAN	T	.3651	.1639	346
SLOPSIN	D	.0309	.2720	346
SLOPCOS	F	.0943	.2770	346
ELEV	E	4790.7514	554.3344	346
D1	S_1	.3578	.1974	346
D2	S_2	.2832	.4512	346
D3	P_1	.0231	.1505	346
D4	P_2	.7341	.4424	346
D5	P_3	.1936	.3959	346
D7	P_4	.0231	.1505	346

R^2

Multiple R	.38419
R square	.14761
Standard Error	2.74898

Analysis of Variance

Source	DF	Sum squares	Mean square	F
Regression	15	431.83592	28.78906	3.81
Residual	330	2493.77102	7.55688	

Variables in the Equation

Variable	B	Beta	Standard error B	F
D7	-.6384177+000	-.03300	1.35668	.221
AGE	-.7744395-001	-.09048	.05823	1.769
BAF03	.6150742-002	-.07458	.00499	1.521
DFIBA	-.2073162-002	-.01588	.01010	.042
DFOBA	.5874758-002	.09028	.00389	2.279
HAZIDX	.1952539+000	.07685	.15204	1.649
SLOPTAN	-.2923995+001	-.16461	1.04204	7.874
SLOPSIN	-.9561879+000	-.08930	.56607	2.853
SLOPCOS	.2253486+001	.21437	.67136	11.267
ELEV	.9370502-003	.17844	.00033	7.827
D1	.7756099+000	.13247	.47843	2.628
D2	.5634252+000	.08730	.51047	1.218
D3	.1796128+001	.09283	1.38601	1.679
D4	.1755348+000	.02667	.95721	.034
D5	.1615043+001	.21947	.99748	2.622
(constant)	-.2496593+001			

Regression 4. Habitat Type Group III

This regression of habitat type group III data was significant at $p \leq .05$ (table 9). A much improved R^2, 0.64, was obtained in spite of the relatively small sample size. Analysis of standardized residuals plotted against standardized predicted $\hat{Y}$ values showed the same slight pattern trend noted in regressions 1, 2, and 3. Basal area of Douglas-fir overstory within plot and hazard index were the more important independent variables in this regression. Hazard index, a value representing the potential of WSBW to interfere with host regeneration establishment, was barely significant in the regression. The sign of the coefficient is negative and corresponds to what one may expect; high hazard is associated with reduced host seedling numbers. The "F" value for age was highest in this regression, possibly reflecting improved site conditions.

Table 9.--Summary statistics, R^2, and analysis of variance for regression #4

Summary Statistics

Variable name	Model ident.	Mean	Standard dev.	Cases
DFLINGS	Y	1.4595	1.9521	37
AGE	A	10.6757	1.7329	37
BAF03	B	2.1622	7.8652	37
DFIBA	Z	1.9281	4.5972	37
DFOBA	J	39.6754	42.4085	37
HAZIDX	W	1.5111	.5213	37
SLOPTAN	T	.4108	.1327	37
SLOPSIN	D	.2485	.2986	37
SLOPCOS	F	-.0936	.1715	37
ELEV	E	4959.4595	408.5608	37
D1	S_1	.1892	.3971	37
D2	S_2	.0270	.1644	37
D3	P_1	.0270	.1644	37
D4	P_2	.0541	.2292	37
D5	P_3	.8919	.3148	37
D7	P_4	.0000	.0000	37

	R^2
Multiple R	.80398
R square	.64638
Standard Error	1.48496

Analysis of Variance

Source	DF	Sum squares	Mean square	F
Regression	14	88.67680	6.33406	2.87
Residual	22	48.51239	2.20511	

Variables in the Equation

Variable	B	Beta	Standard error B	F
AGE	.2416056+001	2.14475	1.72874	1.953
BAF03	.2298266+000	.92598	.05852	15.424
DFIBA	.9116548+000	2.14691	.75820	1.446
DFOBA	-.1412742+000	-3.06907	.10212	1.914
HAZIDX	-.1008171+002	-2.69240	6.64794	2.300
SLOPTAN	-.1834379+000	-.01247	4.16272	.002
SLOPSIN	.1014450+001	.15520	3.34960	.092
SLOPCOS	-.6415528-001	-.00564	2.50766	.001
ELEV	.1549645-001	3.24325	.01169	1.758
D1	.1939601+001	.39451	2.76545	.492
D2	.3366557+001	.28352	3.09315	1.185
D3	-.3282967+002	-2.76476	24.46057	1.801
D4	-.3283145+002	-3.85548	24.56595	1.786
D5	-.3294122+002	-5.31210	24.71246	1.777
(constant)	-.5120155+002			

These regressions represent a first attempt at interrogating a rather large data base. There appears to be some consistency between these regressions in that basal area of Douglas-fir overstory either within or adjacent to the cut stand is directly related to numbers of Douglas-fir seedlings. The site variables of slope and aspect also are significant in three of the four models, indicating a direct influence. Hazard index was statistically important only in model 4.

In none of the regressions was stand age a statistically significant independent variable. The sample consisted of a fairly good distribution of stand ages and we expected that it would be one of the most important variables. Even so, there was a tendency for "F" of the partial regression coefficient to increase as site conditions improved between habitat type groups. It is possible that WSBW activity on the more severe sites interacts with site variables to limit Douglas-fir regeneration. One would expect the suppression to be most pronounced on the more severe sites; this could override the stand age variable.

Notwithstanding the obvious weaknesses in the predictive equations, we used them to compare predicted Douglas-fir seedlings per plot between habitat type groups. The approach was similar to that used by Stage (1976) and Ferguson and others (1980) in that we used the slope/aspect interaction to predict numbers of seedlings; other variables were held constant at their mean values. The specific model used was that given on page 17. The predictive equations then are simplified to:

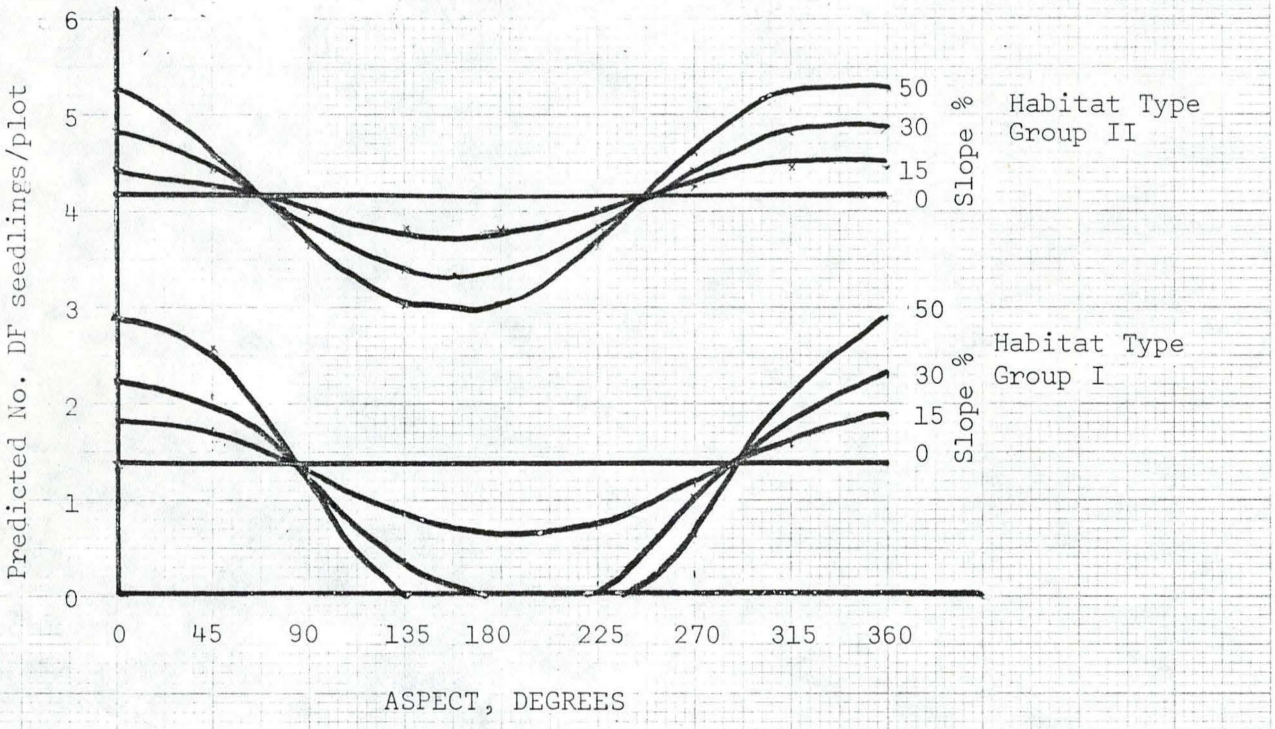
$Y = 1.3707 - 0.9162*\text{slope} + 0.6060*(\text{slope}*\sin\alpha) + 4.000*(\text{slope}*\cos\alpha)$
for group I (α = aspect) and:

$Y = 4.1516 - 0.0292*\text{slope} - 0.9562*(\text{slope}*\sin\alpha) + 2.2153*(\text{slope}*\cos\alpha)$
for group II. Dummy variables were set to D_2 (site prep. ± mechanical) and D_5 (physiography = moist slope). Predicted numbers of seedlings/plot were substantially higher in group II than in group I over the range of slopes and aspects used in the predictions (fig. 2). The curve forms are very similar to those developed by Stage (1976) and Ferguson and others (1980), even though we predicted a discrete variable, whereas Ferguson and others (1980) predicted a continuous variable (probability of stocking).

To avoid problems encountered with regressing a discrete variable against a number of independent variables, we plan to transform the number of seedlings/plot variable to a continuous form and reanalyze the data. Nevertheless, there appear to be substantial differences between the two habitat groups in terms of seedling densities. We are pursuing analyses to determine whether these differences are solely site-related or whether WSBW is an important interacting variable.

We are in the process of testing various combinations of independent variables against density of conifer seedlings. Also, we are testing data transformations so that the slight pattern noted in the graphs of residuals can be eliminated. So far we have tested only Douglas-fir seedling density as a dependent variable. By combining all seedlings into a probability of stocking variable, a good deal more of the model variation may be explained relative to stand structure, site factors, and WSBW.

Figure 2. Effect of the slope/aspect interaction on density of Douglas-fir seedlings in two habitat type groups



Models of seedling growth also are being developed at this time. However, results of data analyses are not yet ready for reporting. A good deal of time has been allocated to development of computer programs to organize and combine data files so that various statistical packages can be applied. This is now completed and the programs are flexible so that the data from any year can be handled. At this time data analysis is a continuing task. We are searching for the best possible fit of our data to a system of models that we anticipate will describe the relationship of seedling establishment, growth, and development to WSBW perturbation and varying stand conditions.

PERIODICITY, INTENSITY, AND HAZARD OF PAST WSBW OUTBREAKS

We developed a method in which data from increment cores of host/nonhost tree pairs in residual stands adjacent to the harvest cuts are used to infer WSBW activity during the period 1956-1978. A manuscript, "Radial Increment Analysis to Index Past Western Spruce Budworm, Choristoneura occidentalis Freeman, Activity in Western Montana," by C. E. Carlson and W. McCaughey, 1981, has been completed and sent out for review. This paper is intended to be published as an INT Research Note. The paper describes a growth function, which is the cumulative sum of squared mean annual radial increment. Growth function curves of WSBW host are compared to those of nonhost within stands. Negative inflections of host curves relative to nonhost are quantified and transformed to a severity index which represents the apparent strength of the inferred WSBW activity. A hazard index is proposed which adjusts effects of WSBW on regeneration establishment; it may be suitable for regression analyses relating WSBW activity to regeneration probability in cutover stands. Graphs of this growth function for stand 148 at First Creek are shown in figure 3. The dashed portion of the host curve is an approximation of what growth should have been in the absence of WSBW. Table 10 lists severity and hazard indexes for all stands sampled in 1979. WSBW activity was inferred for 38 of the 46 randomly selected stands. Accelerated growth of the nonhost was noted in 17 of the 38 stands with WSBW history. Apparently, nonhost trees are released at the expense of WSBW-infested host; additional work is justified on this theme. For a more detailed account of our method to assess past WSBW activity please refer to the manuscript by Carlson and McCaughey (1981) cited previously.

FIGURE 3 ACCELERATION OF PONDEROSA PINE DURING INTERPRETED WSBW INFESTATION.

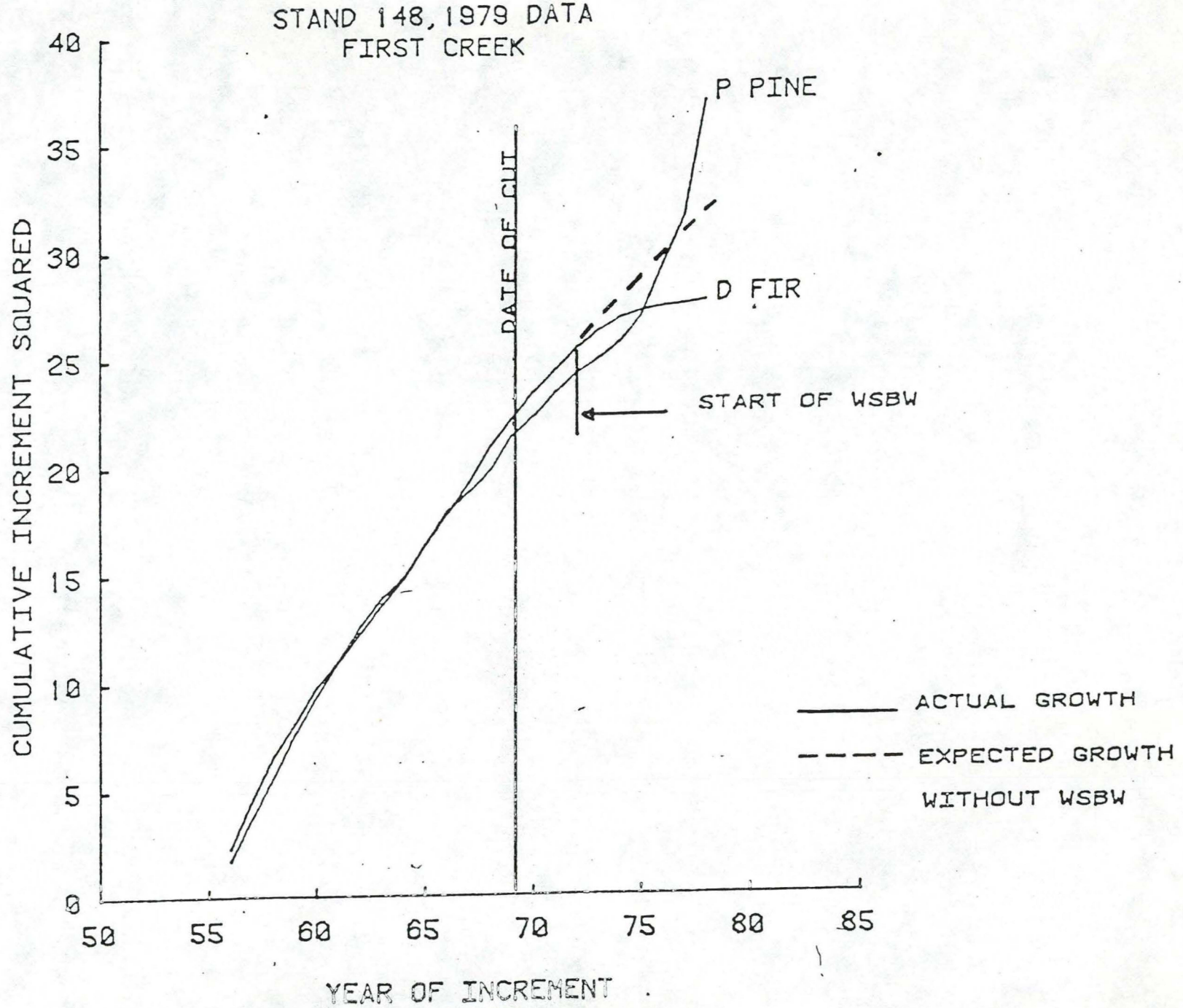


Table 10.--WSBW infestation history and severity rating for stands sampled in 1979

	Infestation Number	Infestation start		Infestation end						Severity index	Weight factor	Hazard index	Species[1]
		Year	Actual growth	Year	Actual growth	Proj. growth	5-3	6-3	7÷8				
Column	1	2	3	4	5	6	7	8	9	10	11	12	13
Stand #													
002	1	1964	17.98	1977	25.78	39	7.8	21.02	0.63	0.37	4	2.52	DF
019	1	1968	5.94	1975	10.44	14	4.5	8.06	.56	.44	4	1.76	DF
020	1	1960	7.86	1974	13.73	28	5.87	20.14	.29	.71	4	2.84	DF
025	1	1958	4.71	1967	15.11	19	10.4	14.29	.73	.27	1	.27	DF
026	1	1972	40.48	1978	44.36	54	3.88	13.52	.29	.71	2	1.42	DF
031	1	1966	4.58	1974	8.91	12	4.33	7.42	.58	.42	4	1.68	DF
035	1	1958	3.62	1974	15.0	23	11.38	19.38	.59	.41	4	1.64	DF
054	1	1966	2.22	1970	2.70	3	.48	.78	.62	.38	1	.38	DF
054	2	1971	2.79	1974	2.94	3	.15	.21	.71	.29	4	1.16	DF
066	1	1969	63.45	1978	79.27	105	15.82	41.55	.38	.62	2	1.24	GF
066	1	1971	63.09	1978	68.86	87	5.77	23.91	.24	.76	2	1.52	DF
069	1	1964	22.82	1974	26.3	40	3.48	17.18	.20	.80	4	3.20	DF
069	1	1964	118.85	1978	136.82	182	17.97	63.15	.28	.72	4	2.88	SAF
070	1	1964	6.51	1975	10.99	13	4.48	6.49	.69	.31	4	1.24	DF
073	1	1958	31.05	1962	56.0	71	24.95	39.95	.62	.38	1	.38	DF
074	1	1958	6.25	1974	30.41	55	24.16	48.75	.50	.50	4	2.0	DF
100	1	1958	30.41	1963	52.35	62	21.94	31.59	.69	.31	1	.31	DF
102	1	1971	11.42	1978	13.49	14	2.07	2.58	.80	.20	4	.80	DF
124	1	1967	17.66	1974	21.89	29	4.23	11.34	.37	.63	4	2.52	DF
126	1	1959	33.45	1978	96.22	144	62.77	110.55	.57	.43	4	1.72	DF
128	1	1971	31.56	1978	33.48	45	1.92	13.44	.14	.86	4	3.44	DF
129	1	1958	3.81	1977	11.66	24	7.85	20.19	.39	.61	4	2.44	DF
127	1	1956	2.43	1978	37.94	52	35.51	49.57	.72	.28	4	1.12	DF
131	1	1958	1.82	1978	7.41	15	5.59	13.18	.42	.58	4	2.32	DF
133	1	1958	2.18	1978	11.42	17	9.24	14.82	.62	.38	4	1.52	DF
135	1	1967	4.87	1978	6.14	8	1.27	3.13	.41	.59	4	2.36	DF
136	1	1958	1.28	1964	2.32	4	1.04	2.72	.38	.62	4	2.48	DF
137	1	1965	50.21	1975	71.76	96	21.55	45.79	.47	.53	4	2.12	DF
138	1	1965	16.66	1974	21.35	30	4.69	13.34	.35	.65	4	2.60	DF
139	1	1966	22.88	1974	29.60	36	6.72	13.12	.51	.49	4	1.96	DF
140	1	1962	4.90	1973	6.99	8	2.09	3.1	.67	.33	4	1.32	DF
141	1	1958	4.15	1968	9.77	21	5.62	16.85	.33	.67	1	.67	DF
142	1	1970	138.18	1978	150.44	188	12.26	49.82	.25	.75	4	3.00	DF
145	1	1958	1.99	1963	3.03	5	1.04	3.01	.35	.65	1	.65	DF
148	1	1972	25.38	1978	27.55	32	2.17	6.62	.33	.67	4	2.68	DF
149	1	1971	60.34	1978	64.41	74	4.07	13.66	.30	.70	2	1.40	DF
150	1	1970	53.28	1978	61.21	71	7.93	17.72	.45	.55	4	2.20	DF
151	1	1959	7.51	1964	17.34	24	9.83	16.49	.60	.40	1	.40	DF
151	2	1967	23.62	1978	32.12	44	8.5	20.38	.42	.58	4	2.32	DF
152	1	1958	9.40	1964	20.41	24	11.01	14.6	.75	.25	1	.25	DF
152	2	1972	36.9	1978	41.87	46	4.97	9.1	.55	.45	2	.90	DF
153	1	1958	3.57	1977	16.02	33	12.45	29.43	.42	.58	4	2.32	DF
154	1	1967	62.89	1975	76.37	92	13.48	29.11	.46	.54	1	.54	DF
156	1	1960	22.47	1963	28.06	32	5.59	9.53	.59	.41	1	.41	DF
156	2	1969	52.87	1978	60.62	83	7.75	30.13	.26	.74	1	.74	DF
158	1	1960	10.28	1978	20.45	39	10.17	28.72	.35	.65	-	--	DF
005	0									0		0	DF
021	0									0		0	DF
023	0									0		0	DF
130	0									0		0	DF
132	0									0		0	DF
134	0									0		0	DF
144	0									0		0	DF
146	0									0		0	DF
157	0									0		0	DF
159	0									0		0	DF

[1]DF = Douglas-fir; GF = grand fir; SAF = subalpine fir.

SAMPLE SIZE

Our proposals advocate a sampling precision for continuous variables such that

$$\frac{T_{05} * SE_{\bar{x}}}{\bar{x}} \leq 0.20$$

where $T_{05} * SE_{\bar{x}}$ is 0.5* (width of confidence interval) around the mean. All 1979 data were analyzed for conformance to this standard and results were transmitted to CANUSA West in "Interim Report to CANUSA West" dated January 1981, by C. E. Carlson. This analysis refers, in most cases, to established management seedlings. Continuous variables measured in this study were seedling height, crown length, vigor, leader growth, crown width, d.b.h., length of top kill, and proportion of terminals with WSBW feeding. Discrete variables to which the sampling formula can also be applied are seedling age, slope, aspect, seedlings per plot, and current and past damage. Overstory (residual, mature stand) continuous variables were basal area per acre and trees per acre, by species. Nonnumeric variables (attributes) which are used for data classification and are not subject to sample size analysis are cutting system, habitat type, site preparation, physiography, and seedling type (planted or natural, established or nonestablished, advanced or subsequent, and dead or alive).

The equation utilized to estimate what the sample size should have been to satisfy our requirements is:

$$N = \frac{S^2 \, T_{05}^2}{d^2}$$

where S = sample standard deviation

T_{05}^2 = student's T squared at probability = 0.05

d = half the desired confidence interval, in our case $0.20 \, \bar{x}$

$\bar{x}$ = sample mean for the variable under consideration.

Then a comparison of actual N to desired N quickly demonstrates whether we have undersampled or oversampled, depending upon the classification criteria used.

The most abundant WSBW host species sampled was Douglas-fir, an expected outcome of sampling within the Douglas-fir climax series. Most variables on Douglas-fir were adequately sampled in the clearcut and shelterwood systems, but not so in the seed tree and selection systems. For all other species, sampling precision was generally below our criterion. A summary of results is given in table 11.

Table 11.--Summary of sample adequacy for 12 variables and 9 species within 4 silvicultural systems. 1979 data from Douglas-fir habitat types, established management seedlings

Species	CLEARCUT		SHELTERWOOD		SEED TREE		SELECTION	
	No. of variables with adequate sample size	No. of variables with inadequate sample size	No. of variables with adequate sample size	No. of variables with inadequate sample size	No. of variables with adequate sample size	No. of variables with inadequate sample size	No. of variables with adequate sample size	No. of variables with inadequate sample size
Western larch[1]	1	8	0	9	5	5	0	8
Douglas-fir	9	2	9	2	6	5	5	6
Grand fir	1	8					2	8
Lodgepole pine	6	1	0	8	1	7	0	7
Subalpine fir	1	9					1	10
Ponderosa pine	7	1	3	6			0	7
Western redcedar								
Engelmann spruce					3	6		
Cottonwood					0	8		

[1]The number of variables per cell does not necessarily equal 12 because either the species was not encountered in the cell, or the variable is one not measured on that species. See the master proposal for a detailed explanation.

The total number of seedlings of any species needed to attain a desired sampling precision for a given variable varies directly with the substructure of the experiment; i.e., greater numbers of classification variables require that more seedlings be sampled to reach sampling goals within a cell. Because our study is based on sampling within a systematic plot design, the number of seedlings sampled varies, more or less, with the number of plots sampled. Therefore, to attain sampling precision for those variables which were below the criterion, we would need to increase the number of plots. However, remember that a number of different variables are measured on each seedling, none of which have the same standard error. So we are faced with the question: Do we sample until the criterion is met for all variables, or do we meet the limit set only for the most important variables? We opt for the latter, recognizing that it is cost prohibitive to adequately sample for all variables.

The most important growth variables in this study are seedling height, vigor, leader growth, current damage, and proportion damaged. Our sample size was generally adequate for these variables on Douglas-fir over all four cutting systems.

Our 1980 fieldwork was done within the subalpine fir climax series which is colder and wetter than the Douglas-fir series. Because the probability of successful regeneration establishment is higher in the SAF series, we expect to have sampled more species more of the time. This should reduce standard errors and result in a closer match between theoretical and actual sample size than we experienced for the Douglas-fir series. The grand fir series, which we have proposed to sample in 1981, is warm-wet relative to the Douglas-fir series, and similar to the subalpine fir series, and should have more species more of the time. Therefore, we expect that our sample design (48 stands represented by four cutting systems, three size classes, and four replications) will be adequate to assess the effects of WSBW in the regeneration-growth process.

This analysis of sampling precision was based only on data from within the Douglas-fir climax series. However, even though the habitat type of a stand may be Douglas-fir, topographic variation within the stand may result in some plot habitat types being of a different series. Thus, about one-third of our 1979 plots actually were not Douglas-fir habitat types. We expect similar overlap for our 1980 and 1981 data. This means that continued sampling as per our original proposal will increase the plots sampled in each series, should reduce standard errors, and should result in a sampling precision closer to our ideal. We believe we are very close to being "on track" with our design; we certainly are not oversampling relative to the variability encountered so far, and it looks like most variables may be adequately accounted for, providing the financial support is forthcoming to finish field sampling in the summers of 1981 and 1982.

Status of 1980 Data

Our 1980 fieldwork concentrated on data collection in subalpine fir habitat types. Fourty-four extensive stands were sampled; basic data for each stand sampled in 1979 and 1980 are in table 12. Data collection did not deviate from methods detailed in the 1980 study plan. All data has been keypunched, entered on disc and tape files, and has been edited for corrections. Four data sets exist:

1. Regeneration data

2. Adjacent stand data

3. Increment core data

4. Population fix data (larval[8], egg mass, and defoliation data)

These files are maintained at the Fort Collins Computer Center. In 1979, 795, and in 1980, 705, plots were sampled in the extensive stands; the total for the 2 years is 1,500. Four new intensive sites were established and sampled and the three 1979 intensive sites were resampled according to study design. Table 13 lists pertinent information for the intensive sites. No statistical analyses of 1980 data have yet been done; we have had a full schedule just collecting and managing this data.

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[8]Charles Tiernan collected the larval data.

Table 12.--Extensive stands--sampling completed

Stand name	Stand No.	Acres	Habitat type	Treatment type	Location	Elev. (ft.)	# of plots	Harvest date
1979								
Thibodeau	002	39	PSME/SYAL	Selection	T14N R16W S21	3700	21	1967
Lincoln	005	280	PSME/SYAL	Selection	T14N R08W S21	4600	23	1969
Gold Creek	019	36	PSME/SYAL	Seed Tree	T09N R11W S35	5400	27	1967
Skimmerhorn	020	50+	PSME/VAGL	Seed Tree	T13N R14W S26	5000	37	1964
Reynolds City	021	33	PSME/CARU	Seed Tree	T12N R13W S6,7	5600	26	1964
Reynolds City	023	5	PSME/LIBO	Clearcut	T12N R13W S06	5600	11	1964
Meadow Creek	031	4	PSME/SYAL	Clearcut	T02N R17W S19	5400	9	1965
Coal Creek	035	20	PSME/CARU	Clearcut	T02S R22W S17	5100	21	1965
Grouse Ridge	041	5	PSME/CARU	Clearcut	T12N R01E S06	6600	11	1961
Tyler Creek	054	4	PSME/VAGL	Shelterwood	T10N R15W S05	5700	13	1971
Lion Point	066	42	PSME/CARU	Selection	T13N R25W S36	4000	24	1967
Laird Creek	069	24	PSME/VAGL	Shelterwood	T01N R20W S04	5200	19	1969
Slate Point	070	55	PSME/VAGL	Shelterwood	T02S R22W S02	6100	30	1966
Surveyor Creek	073	51	PSME/PHMA	Selection	T13N R25W S36	4300	19	1968
Jennings Camp Cr.	074	166	PSME/SYAL	Shelterwood	T02N R18W S21	5700	35	1967
Howard Creek #2	100	4	PSME/VAGL	Selection	T12N R24W S24	4900	7	1966
Howard Creek #1	102	4	PSME/VAGL	Selection	T12N R23W S18	4800	8	1974
Park Creek	124	31	PSME/PHMA	Seed Tree	T11N R18W S06	4800	19	1972
Blue Mountain	127	--	PSME/PHMA	Clearcut	T13N R20W S32	4600	28	1962
Blue Mountain	128	36	PSME/PHMA	Shelterwood	T12N R20W S05	4400	22	1971
Deer Creek	129	43	PSME/CARU	Clearcut	T13N R14W S29	5400	21	1964
Upper Union Cr. #1	130	81	PSME/VAGL	Seed Tree	T13N R14W S29	5600	34	1970
Deer Creek	131	31	PSME/VAGL	Seed Tree	T13N R14W S28	5000	20	1964
Upper Union Cr.	132	49	PSME/LIBO	Selection	T13N R14W S29	5700	25	1968
Upper Union Cr. #2	133	5	PSME/VAGL	Seed Tree	T13N R14W S30	5600	6	1970
Grouse Ridge	134	28	PSME/CARU	Shelterwood	T12N R01W S06	6500	13	1969
Fletcher Pass	136	3	PSME/VAGL	Clearcut	T14N R06W S15	6200	7	1962
Piquette Creek #1	137	2	PSME/CARU	Clearcut	T01N R21W S10	4900	6	1966
Piquette Creek #2	138	20	PSME/CARU	Clearcut	T01N R21W S02	4900	18	1966
Piquette Creek	139	2	PSME/CARU	Shelterwood	T01N R21W S01	5500	7	1966
Overwhich Creek	140	61	PSME/CARU	Clearcut	T02S R22W S14	5200	17	1969
Overwhich Creek	141	7	PSME/CARU	Shelterwood	T02S R22W S11	5100	13	1974
Cromwell Creek	142	4	PSME/CARU	Selection	T15N R23W S13	3600	12	1968
Gillespie Creek	144	50	PSME/PHMA	Seed Tree	T11N R16W S24	4800	24	1968
Kitchen Creek	145	50+	PSME/PHMA	Selection	T11N R16W S22	5600	17	1970
Gold Creek	146	150	PSME/SYAL	Clearcut	T08N R11W S02	5300	27	1965
First Creek #1	148	87	PSME/SYAL	Selection	T16N R25W S08	4500	23	1969
First Creek #2	149	45	PSME/PHMA	Selection	T16N R25W S08	4900	25	1968
First Creek #3	150	5	PSME/PHMA	Selection	T16N R25W S17	4000	6	1971
First Creek #4	151	27	PSME/CARU	Shelterwood	T16N R25W S09	4300	16	1968
First Creek #5	152	23	PSME/PHMA	Shelterwood	T16N R25W S09	4200	20	1966
First Creek #6	153	51	PSME/PHMA	Clearcut	T16N R25W S09	4500	17	1963
Valley Creek	154	5	PSME/PHMA	Seed Tree	T16N R21W S12	4400	11	1973
TOTAL							795	

Table 12.--Extensive stands--sampling completed (con.)

Stand name	Stand No.	Acres	Habitat type	Treatment type	Location	Elev. (ft.)	# of plots	Harvest date
1980								
Marshall Creek	220	2	ABLA/VASC	Shelterwood	T11N R22W S10	5400	7	1963
Marshall Creek	221	29	ABLA/XETE	Selection	T11N R22W S10	5100	16	1967
Second Creek	222	42	ABLA/XETE	Selection	T17N R25W S35	6000	26	1965
S. Fork Lolo	223	4	ABLA/MEFE	Shelterwood	T11N R22W S14	5800	12	1973
S. Fork Lolo	224	6	ABLA/MEFE	Shelterwood	T11N R22W S23	5600	11	1973
Blue Mountain	225	16	ABLA/XETE	Shelterwood	T12N R21W S14	5800	18	1972
Blue Mountain	226	78	ABLA/XETE	Seed Tree	T12N R21W S14	5900	24	1972
Blue Mountain	227	4	ABLA/CLUN	Shelterwood	T12N R20W S07	5800	8	1962
Blue Mountain	228	20	ABLA/CLUN	Shelterwood	T12N R21W S12	5800	15	1962
Blue Mountain	229	31	ABLA/XETE	Clearcut	T12N R21W S04	5700	25	1967
Blue Mountain	230	77	ABLA/MEFE	Shelterwood	T12N R21W S2,11	5300	26	1965
Cedar Creek	231	12	ABLA/XETE	Clearcut	T15N R27W S07	7100	14	1966
Trail Creek	232	109	ABLA/XETE	Seed Tree	T17N R14W S18	4500	22	1965
Sawyer Creek	234	31	ABLA/XETE	Seed Tree	T17N R15W S03	5600	15	1965
Unident	233	38	ABLA/XETE	Seed Tree	T18N R15W S34	5800	14	1966
Schwartz Creek	235	4	ABLA/XETE	Clearcut	T11N R17W S30	5200	6	1960
Gilbert Creek	236	63	ABLA/CLUN	Shelterwood	T10N R18W S01	5300	20	1962
Schwartz Creek	237	4	ABLA/CLUN	Shelterwood	T11N R18W S23	5000	7	1964
Cinnamon Bear	238	23	ABLA/MEFE	Clearcut	T09N R18W S15	6200	18	1967
Cinnamon Bear	239	67	ABLA/XETE	Shelterwood	T09N R18W S10,11	6300	25	1969
Cedar Creek	240	4	ABLA/CLUN	Clearcut	T15N R27W S05	5000	8	1967
Cedar Creek	241	32	ABLA/MEFE	Clearcut	T15N R27W S07	5800	20	1966
Deer Creek	242	3	ABLA/XETE	Seed Tree	T12N R18W S20	6200	11	1974
Twin Creek	243	8	ABLA/XETE	Shelterwood	T14N R17W S20	5700	14	1973
Twin Creek	244	54	ABLA/MEFE	Shelterwood	T14N R17W S20	6100	26	1973
Lolo Creek	245	3	ABLA/LIBO	Seed Tree	T11N R24W S24	4400	10	1962
Lolo Creek	246	12	ABLA/XETE	Seed Tree	T11N R24W S24	4200	16	1962
Mormon Peak	247	58	ABLA/XETE	Selection	T11N R21W S13	5400	26	1960
Granite Creek	248	90	ABLA/CLUN	Clearcut	T11N R24W S22	5000	25	1965
Howard Creek	249	12	ABLA/XETE	Selection	T12N R23W S18	5000	13	1966
Cinnamon Bear	250	3	ABLA/XETE	Clearcut	T09N R18W S15	6200	5	1967
Alder Creek	251	4	ABLA/XETE	Clearcut	T08N R18W S04	6500	8	1971
Nugget Creek	252	88	ABLA/CLUN	Clearcut	T17N R24W S18	4800	23	1973&74
Finnely Creek	253	80	ABLA/CLUN	Seed Tree	T16N R16W S28	4800	22	1974
Camp Creek	254	61	ABLA/XETE	Clearcut	T18N R15W S21	5400	22	1970
McCabe Creek	255	69	ABLA/XETE	Seed Tree	T16N R12W S28	5000	21	1967
McCalla Creek	256	65	ABLA/XETE	Clearcut	T09N R21W S35	6200	18	1968
Mormon Peak	257	16	ABLA/VASC	Selection	T11N R21W S14	6000	9	1962
Eightmile Creek	258	5	ABLA/XETE	Selection	T11N R18W S34	5500	8	1974
Laird Creek	259	76	ABLA/XETE	Clearcut	T01N R20W S16	6100	25	1967
Ninemile Creek	260	18	ABLA/XETE	Seed Tree	T16N R22W S27	5800	17	1970
Mud Creek	261	14	ABLA/XETE	Selection	T15N R22W S22	5400	12	1961
Mud Creek	262	10	ABLA/XETE	Selection	T15N R22W S22	5400	9	1961
Willow Creek	263	4	ABLA/XETE	Clearcut	T07N R19W S36	6500	8	1964
TOTAL							705	

Table 13.--Intensive stands established in 1979 and 1980

Stand name	Stand No.	Acres	Habitat type	Treatment type	Location	Elev. (ft.)	No. of plots	Harvest date
Valley Creek #1	126	30	PSME/PHMA	Selection	T16N R21W S03	3900	33	1972
Chamberlain Creek	135	186	PSME/CARU	Seed tree	T14N R13W S20	4800	55	1968
Blue Mountain	143	80	PSME/PHMA	Clearcut	T13N R20W S32	4600	46	1962
First Creek	200	13	ABGR/CLUN	Clearcut	T16N R25W S15	4100	28	1960
Second Creek	205	20	ABGR/CLUN	Shelterwood	T16N R25W S14	3800	25	1960
Valley Creek #2	210	65	ABLA/XETE	Selection	T16N R20W S08	4400	50	1972
Union Peak	215	30	ABLA/LIBO	Seed tree	T12N R14W S04	5800	41	1972

CONCLUSIONS AND RECOMMENDATIONS

Because of the continuing nature of this research, our conclusions at this point in time are tentative. With this in mind, the following points can be made:

1. Past WSBW outbreaks presumably can be dated and indexed for severity and hazard to regenerating stands. This is important to our study in that it provides a measure to relate WSBW activity to the regeneration process.

2. Overstory stand structure influences WSBW damage to regeneration. Regeneration damage tends to increase as the density of overstory host increases.

3. Density of Douglas-fir seedlings is dependent upon a number of site factors. In the more productive habitat types, increasing hazard index appears to result in reduced numbers of host seedlings. Whether this is important in terms of total stocking on good sites has not yet been assessed. Also, our data weakly indicate that WSBW may be interacting with site variables to influence Douglas-fir regeneration.

Looking ahead, and based on data from past harvest cuts, it certainly appears possible to utilize silvicultural techniques to reduce the impact of WSBW on establishment and growth of conifer stands. The following suggestions are merely a beginning look at what we can do. It is first understood that in any harvest cut (or others such as thinning, etc.), the basic ecological criteria for seedling establishment and growth, exclusive of WSBW considerations, must first be met. Within those restrictions, the following ideas appear valid:

1. Reduce the ratio of host/nonhost basal area. In partial cuts, favor the nonhost species.

2. Remove residual host overstory from partial cuts no later than 10 years following establishment of regeneration.

3. For partial cuts, minimize the residual host basal area left either for seed source or shelter.

4. Create a "buffer" by reducing basal area of host species in adjacent stand within 100 meters of the boundary of the adjacent stand.

5. Make cutting units as large as possible commensurate with other management restrictions.

6. When planting, prescribe a good mix of species, but no more than one-third host seedlings.

7. During stand development, maintain the minimum number of seedlings-per-acre/basal area relative to other management objectives, and maintain a minimum ratio of host/nonhost growing stock (1:3 or 1:4).

These actions, if and when invoked over large enough land bases (sub-compartment, for example), may influence adult and larval WSBW dispersal, will limit population size, and will significantly reduce present and current WSBW impact on stands managed for fiber production.

WORK REMAINING ON STUDY

As proposed originally, this study was designed to investigate WSBW variation in four silvicultural systems spanning three climax forest series. We have now completed data collection in the Douglas-fir and subalpine fir series; we propose to sample the grand fir series during FY 1981 (summer). Some analyses have been completed of 1979 data but, due to time constraints, none have been done on the 1980 data. Data analysis is ongoing and most regressions and hypothesis testing of 1979 and 1980 data will be finished by September 1981. Fiscal year 1982 will be devoted to remeasurement of intensive sites and final analysis of all data and report writing.

COOPERATION AND COORDINATION

We have coordinated with Dennis Ferguson and Al Stage, Moscow Forestry Sciences Laboratory, for population fix sampling and data collection. Forest Pest Management, Region 1, Missoula, MT, through the help of Larry Stipe, Alice Green, and Carma Gilligan, gave us much needed aid on extraction of egg mass data. Bill Wulf, the CANUSA silvicultural liaison in Timber Management, R-1, Missoula, MT, offered his usual excellent constructive criticism throughout 1980.

PROBLEMS ENCOUNTERED

No significant problems were encountered. After 2 years of data collection, we are on schedule and look forward to completion of major data collection with 1981 sampling in the grand fir series and 1982 remeasurement of intensive stands.

MANUSCRIPTS OR REPORTS PREPARED OR PLANNED

We have submitted for peer review the following manuscript:

Carlson, C. E., and W. McCaughey.
1981. Radial increment analysis to index past western spruce budworm, Choristoneura occidentalis Freeman, activity in western Montana.

This paper is intended to be a Station Research Note.

At the request of Dr. Jim Colbert of CANUSA West, we prepared a document which we entitled "Interim Progress Report to CANUSA West" authored by Clinton E. Carlson. This 25-page document set forth a revised budget for 1981, explained the relationship of extensive sites to intensive sites, and reported analyses of sample size for several study variables.

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